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A COMPARISON OF SOME METHODS
OF ESTIMATING RADIUM

by

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INTRODUCTION

The quantitative determination of the small amounts of radium present in the atmosphere, spring waters, minerals and rocks involves two steps:- (1) The quantitative separation of the radium emanation in a known weight of the sample and (2) measurement of the ionization current produced by the emanation in a calibrated electroscope. Granting that we have accurate methods of separating radium emanation, the other problem of measuring the ionization current and the calibration of the electroscopes for quantitative work must be given careful study, because the results ultimately depend upon the calibration constants of the electroscopes used. In the estimation of radium, the electroscope corresponds to the weights and analytical balance in ordinary quantitative chemical analysis. An electroscope is said to be standardized or calibrated when we know the quantity of radium, (or uranium) represented by some constant of the instrument. These calibrations may be expressed in one of the following forms:-

(1) Grams of radium or uranium represented by a fall of the leaf of the electroscope per scale division of the instrument per minute.

(2) Grams of radium or uranium corresponding to a fall of the leaf of one volt per minute.

(3) Grams of radium or uranium corresponding to one electrostatic unit of current.

(4) Ionization current produced by the radium emanation in equilibrium with one gram of uranium or radium.

The present investigation includes the calibration of three types of alpha ray electroscopes extensively used for the determination of small quantities of radium by the emanation method. The known quantities of the radium emanation required in these experiments were obtained, (1) from uraninite (Pitchblende) of known uranium content, and (2) from a standard radium solution. In this connection a comparative study was made of the types of apparatus employed by several investigators for the separation of the emanation and its transfer to the electroscopes, with a view of standardizing the existing methods for the calibration of electroscopes.

The principal parts of the problem and the order of the topics appear in the table of contents.

STANDARDS FOR CALIBRATING ELECTROSCOPES

Two standards were used as a source of radium emanation in the calibration of the electroscopes, namely, (A) the Boltwood Uranium-Radium-Standard¹, and (B) the Radium Standard of Rutherford-Boltwood, obtained from Boltwood, and described in the American Journal of Science, Volume XXII, page 1, (1906).

A. The Boltwood Standard. Boltwood has suggested that the quantity of radium emanation associated with one gram of uranium in an old mineral, such as pitchblende, be used as a standard of radioactivity. The Boltwood Standard used was a uranium mineral or uraninite of unknown origin, purchased from the firm of Eimer & Amend. I am indebted to Dr. Merle Randall² for the analytical determination of the uranium in the sample of uraninite used. Dr. Randall determined the uranium content by a modification of the method described by Boltwood³. The results of this method gave a mean percentage of uranium in the mineral of 53.46, when referred to the finely powdered material heated two hours at 100° C.

In all the subsequent determinations two forms of the Boltwood Standard were used. In one form small quantities of the uraninite, ranging from 0.005 g. to 0.4756 g. and containing from 0.002 g. uranium to 0.263 g. uranium, were carefully weighed out into small Erlenmeyer flasks of about 100 cc. capacity. The flasks

¹ Randall, M. The Boltwood Standard of Radioactivity, Am. Electrochem. Soc., Vol. 21, 463 (1912).

² Randall, M. Ibid.

³ Boltwood, B.B., Phil. Mag., 9, 603 (1905); See, also Brearley, H., Analytical Chemistry of Uranium.

Sample Flask - Solution Form

Equipped Stopper For Solid Form

PLATE 1

were then numbered, firmly stoppered with solid rubber stoppers, and stored for a month, after which time radioactive equilibrium was attained ⁴. Thirty such samples were stored, and after a month's time were used in obtaining radium emanation for the calibrations of the electroscopes. To separate the emanation, each sample was treated with nitric acid. No experiments were carried out to determine whether any radium remained in the insoluble residue. By means of several forms of apparatus, (later described), the emanation was transferred to a burette, and then to an exhausted electroscope.

To facilitate transfer of stoppers, and to obviate any loss of emanation which might possibly occur during the change of stoppers incident to the heating of the samples with nitric acid, duplicate, well fitted stoppers were prepared for each Erlenmeyer flask. Each duplicate two-holed stopper was equipped with a short dropping-funnel and a right-angled glass delivery tube fitted with a short connecting rubber tube and clamp, as shown in plate No. I.

Inasmuch as the weighed samples were stored in the solid form before the emanation was separated, this form of the Boltwood Standard will be referred to as the "solid form".

The second form of the Boltwood Standard consisted of two stock solutions of the uraninite, each stock solution having a definite uranium or radium content ⁵. The first stock solution was

⁴ Rutherford, E., Radioactivity, 2d. Edition, p. 372.

⁵ Eve, A.S., Am. Jour. Sci., 22, 4 (1906). Phil. Mag., 18, 102 (1909).

prepared by dissolving 6.0587 grams of the uraninite in concentrated nitric acid, and then adding distilled water to make 1000 cc. The second stock solution contained 1.0540 grams of uraninite per liter. These stock solutions were used in preparing individual samples of known and widely differing radium content.

Forty four samples in all were put up in storage flasks of about 100 cc. capacity, and were stored for periods of a month or over. Each flask was closed with a firmly fitting one-holed rubber stopper containing a short glass tube and strong rubber tube with a screw clip. The same precaution was exercised in connecting these flasks to the gas burette as in the case of the "solid form". This form of flask obviated boiling with nitric acid and the use of a drop-funnel, necessary in the former samples, as connection was made directly to the burette without removing the stopper, and heating was immediately commenced. This form of sample will be referred to as the "solution form" of the Boltwood Standard.

B. The Radium Standard. It was obtained from Boltwood, and consisted of ten cubic centimeters of radium bromide contained in a scrupulously clean tube of clear glass, drawn out and sealed off at both ends. This radium bromide constituted a portion of the original Rutherford-Boltwood Standard solution⁶ and on the basis of the new International Standard contained 0.165×10^{-5} mg., or 0.165×10^{-8} g. of radium per cubic centimeter. The radium content of the ten cubic centimeters was therefore 1.65×10^{-8} g.

⁶ Am. Jour. Science. 22, 1, (1906).

Special care was taken in opening the tube containing the standard radium bromide, to avoid loss of even a drop of the solution. A scratch was made with a file on each of the drawn ends of the tube, and the ends were broken off over a clean beaker. The solution was allowed to trickle out over a glass rod into the beaker containing about 200 cc of distilled water. The rod, tube, and broken ends were thoroughly washed and the washings allowed to flow into the beaker. The solution was then boiled to expel all emanation, and then transferred to a liter flask, the beaker rinsed several times, and the rinsings transferred to the liter flask until a bulk of 1000 cubic centimeters was obtained.

This liter of radium bromide solution, containing 1.65×10^{-11} g. radium per cc, was used as a stock solution for the preparation of two series of seven samples each. One-half of the samples were put up in 200 cc. Erlenmeyer flasks, and later the rest in 100 cc. Jena flasks to resist a high vacuum. The reason for the change in flasks will become apparent when the methods for boiling off emanations are described. The individual samples were boiled just before storage.

Each sample of radium bromide solution was stored for 3.83 days -- half period of radium emanation -- as lack of sufficient time precluded storing for the full period of recovery, -- a month.

As the operations necessary in boiling off the emanation, transferring to an exhausted electroscope, and making the

necessary readings consumed approximately one hour's time, the samples were stored about one hour apart to insure accurate timing of each sample.

The following three tables of record show in tabulated form the uranium and radium content of the different samples. The ratio 3.4×10^{-7} is given by Rutherford and this value has been used in the final summary.

TABLE NO.1

"Solid Form" of Boltwood Uranium Standard

No. of Sample	Weight of Uranium taken in mg.	Milligrams of Uranium	Grams Radium $\times 10^{10}$
1	103.0	55.0	170.6
2	113.6	60.7	188.2
3	475.6	254.2	788.1
4	221.8	118.5	367.5
5	70.1	37.4	116.1
6	64.3	34.3	106.5
7	147.9	79.0	245.1
8	232.2	113.1	350.7
9	151.6	81.0	251.2
10	35.0	18.7	58.0
11	18.7	9.9	30.9
12	163.4	87.3	270.6
13	59.6	31.8	98.7
14	30.2	16.1	49.9

TABLE NO.1 (Continued)
"Solid Form" of Boltwood Uranium Standard

No. of Sample	: Weight of Urani- : nite taken in mg.:	: Milligrams of: : Uranium	: Grams Radium : $\times 10^{10}$
15	: 5.0	: 2.6	: 8.2
16	: 7.5	: 4.0	: 12.4
17	: 9.0	: 4.8	: 14.9
18	: 22.3	: 11.9	: 36.9
19	: 12.5	: 6.6	: 20.7
20	: 12.0	: 6.4	: 19.8
21	: 470.	: 251.	: 778.
22	: 190.	: 101.	: 314.
23	: 120.	: 064.	: 198.

As some of the samples of uraninite taken were small in weight -- the smallest weighing 5 milligrams, -- and as the accuracy of the final results depended primarily on the accuracy of making the samples, all the gravimetric and volumetric operations appertaining thereto were executed with extreme care and precaution.

TABLE NO.2
"Solution Form" of Boltwood Uranium Standard

No. of Sample	: Weight of Urani- : nite in Solution : in mg.:	: Milligrams of: : Uranium	: Grams Radium : $\times 10^{10}$
1	: 594.1	: 317.6	: 984.5

TABLE NO.2 (Continued)

"Solution Form" of Boltwood Uranium Standard

No. of Sample	: Weight of Urani- : nite in Solution : in mg.	: : Milligrams of : Uranium	: : Grams Radium : $\times 10^{10}$
2	535.5	286.3	887.5
3	468.6	250.5	776.6
4	406.7	217.4	674.1
5	78.7	135.5	420.0
6	253.4	135.5	420.0
7	197.2	105.4	326.8
8	144.1	77.0	238.9
9	120.5	64.4	199.7
10	102.9	55.0	170.5
11	77.1	41.2	127.8
12	736.0	393.4	1,219.7
13	667.0	356.6	1,105.4
14	620.4	331.6	1,018.1
15	30.2	16.1	50.1
16	10.9	5.8	18.0
17	11.0	5.9	18.3
18	21.9	11.7	36.3
19	32.8	17.5	54.4
20	38.8	20.7	64.4
21	46.5	24.9	77.1
22	55.4	29.3	91.0

TABLE NO.2 (Continued)

"Solution Form of Boltwood Uranium Standard"

No. of Sample	: Weight of Urani-:	:	:	:
	: nite in Solution:	Milligrams of:	Grams Radium	
	: in Mg.	: Uranium	: $\times 10^{10}$	
23	50.5	27.0	83.8	
24	53.1	28.3	88.0	
25	12.3	6.5	20.4	
26	16.1	8.6	26.7	
27	20.5	10.9	34.0	
28	24.3	13.0	40.3	
29	30.1	16.1	49.9	
30	35.3	18.8	58.4	
31	45.9	24.5	76.1	
32	23.2	12.4	38.5	
33	50.6	27.0	83.9	
34	54.7	29.2	90.6	
35	61.5	32.9	101.9	
36	50.8	27.1	84.1	
37	77.1	41.2	127.8	
38	35.9	19.2	59.5	
39	22.3	11.9	37.0	
40	12.4	6.6	20.5	
41	16.0	8.5	26.5	
42	24.8	13.2	41.1	
43	34.6	18.5	57.4	
44	20.5	10.9	34.0	

As explained on page 9, two stock solutions of uraninite were used in the preparation of the samples of Table No. 2. The first stock solution contained 6.0587 grams of uraninite per liter, and the second consisted of 1.0540 grams per liter. Samples Nos. 1 to 16 inclusive were made from the first stock solution, and the remainder from the second.

TABLE NO. 3

Samples of Rutherford-Boltwood Standard Solution
of Radium Bromide

No. of Sample	No. of CC. Taken	Grams Radium present in sample; $\times 10^9$	Gms. U. Equivalent of Samples; $\times 10^3$
A	67	1.1055	3.566
B	67	1.1055	3.566
C	70.5	1.1432	3.688
D	74	1.2210	3.939
E	74	1.2210	3.939
F	100	1.6500	5.322
G	100	1.6500	5.322
A ¹	70.5	1.1432	3.688
B ¹	60	.9900	3.193
C ¹	60	.9900	3.193
D ¹	65	1.0725	3.460
E ¹	65	1.0725	3.460
F ¹	55	.9075	2.927
G ¹	55	.9075	2.927

A definite number of cubic centimeters of the stock solution was allowed to run into each Erlenmeyer flask from a burette, and the volume was read off to the second decimal place. The uraninite content of each cubic centimeter of stock solution was known, and from the volume of solution in each flask or sample, the uraninite content of each sample was calculated.

The uranium content of each sample, both solid and solution form, was obtained by multiplying the uraninite content by 53.46 %. The constant, 3.1×10^{-7} , was taken in obtaining the radium equivalent of the samples.

APPARATUS FOR SEPARATING
AND TRANSFERRING THE RADIUM EMANATION

Various types of apparatus have been described by different investigators for separating the emanation and transferring it to the electrosopes. The forms of apparatus used in this investigation appeared to be free from several of the sources of error and difficulties of manipulation connected with some of the types of apparatus employed by different investigators.

Strutt ⁷ used an original apparatus which presented two objectionable features. He found that discontinued boiling was a difficult matter, and that it was highly probable some of the emanation contained in the receiver would not be introduced into the electroscope, on account of some of the gas being entrapped in the connecting tubes.

Randall ⁸ overcame this difficulty considerably by a slight modification of the Strutt apparatus.

Schlundt and Moore ⁹ used an apparatus which was eventually adopted with but a slight modification, so as to avoid the same entrapping of emanation experienced by others.

Boltwood ¹⁰, McCoy ¹¹, and McKenzie ¹² have each devised their own form of apparatus, and these forms were given consideration in the choice of apparatus.

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- ⁷ Strutt, R.J., Proc. Royal Soc. 77, 472 (1906)
⁸ Randal, M., Trans. Am. Electrochem. Soc., 21, 463 (1912)
⁹ Schlundt & Moore, J. Physic. Chem., 9, 320 (1905)
¹⁰ Boltwood, B.B., Am. Jour. Sci., 18, 380 (1904); Nature, 70, 80, (1904); Phil. Mag., 9, 599 (1905)
¹¹ McCoy and Ross, J. Am. Chem. Soc., 29, 1700 (1900)
¹² Soddy and McKenzie, Phil. Mag., 14, 272 (1907).

PLATE 2

It was ultimately decided to use three distinct forms of apparatus for the separation and transfer of the emanation.

The three forms of apparatus used were a modification of the Schlundt-Moore apparatus for boiling off emanations at atmospheric pressure, a modification of the Soddy-McKenzie apparatus for boiling off emanations in vacuo, and a newly devised form of apparatus for transferring the "solution form" of samples directly into the electroscope without boiling.

THE SCHLUNDT and MOORE APPARATUS

This design of apparatus is essentially as described and shown in plate 2. It consists of a gas-burette A, the sample-flask, B, -- connected to the upper side-tube of the burette, the leveling reservoir, C, -- connected to the lower side tube, and U-tube D, sealed to the top of the burette.

The leveling reservoir is attached below the connection for the flask, to decrease the possibility of the escape of emanation through the connecting-tube of the reservoir when the burette becomes filled with the gas contents of the flask. Despite this precaution in construction care must be taken not to lose emanation through the reservoir by the accidental displacement of all the liquid in the burette by steam.

The entire train of apparatus, D, was sealed on to the top of the burette with a glass stop-cock, E, between. This part of the apparatus served a double function. The glass-stoppered U-tube contained a few cubic centimeters of concentrated sulphuric

acid with plugs of glass wool above it on either side. While the sulphuric acid washed the emanation free of moisture and dust particles the wool plugs prevented the spilling of the acid into the connecting tubes. As a precaution to the afore mentioned entrapping of emanation in the connecting tubes, a glass stop-cock, F, was fused to the other side of the T-tube.

This form of apparatus was entirely of glass, excepting the rubber connections to the flask, to the reservoir, and to the electroscope.

Referring back to the two forms of samples of the uraninite, it will be observed that the Schlundt and Moore apparatus is shown with the "solution form" of sample attached.

Care and close attention was required in the manipulation of this apparatus. With stop-cocks E and H closed, freshly boiled distilled water containing a few cubic centimeters of sodium hydroxide was poured into the reservoir until completely filled. Stop-cock, E, was then opened until the burette, A, was filled. Water was added until it reached the bottom of the reservoir, C.

The sample flask was subsequently attached. In attaching the flask, its solid stopper was exchanged for the prepared stopper (described on page 10) as rapidly and carefully as possible, to avoid any possible loss of emanation.

When the "solution form" of sample was attached, the flask was heated a few seconds with stop-cock H closed to create an upward pressure, the stop-cock was then opened and heating

continued until the contents of the flask had boiled about ten minutes. If the boiling became too vigorous, the flame was removed and the leveling reservoir lowered. At intervals during the operation the boiling was done with the leveling reservoir lowered, the flame was removed and the reservoir raised. This caused the water from the burette to fill the flask. After three or four such heatings the greater part of the water through which the emanation passed became heated or boiled, thus decreasing the possible loss of emanation by absorption in the water of the burette.

The gases separated in this manner from the "solution form" of sample were allowed to remain in the burette for at least twenty minutes, and then transferred to the electroscopes.

During this wait the partially exhausted electroscope was attached to the apparatus at G by means of strong rubber tubing. The gases in the burette were transferred to the electroscope by opening stop-cock E and that of the electroscope, keeping F closed, and raising the leveling reservoir. When the level of the water in the burette reached the level of the branch of the T-tube above E, E was closed and F opened cautiously. The current of air entering through F swept the emanation remaining in the connecting tubes into the electroscope. The attachment F was introduced by Randall ¹³.

The operations necessary in boiling the "solid form"

¹³ Randall, M., Ibid. p. 472.

of sample with this apparatus were as follows. The flask was attached as in the previous case, but the solid stopper of the flask was replaced by the prepared stopper (see page 9) containing a drop funnel and a right-angled glass delivery tube.

After attaching the flask, the burette was filled as before, H and E were closed, and a few cubic centimeters of diluted nitric acid was then poured into the drop funnel. The leveling reservoir of the gas burette was lowered below the level of the acid in the funnel; then the pinch-cock of the delivery tube and the stop-cock of the funnel were opened, thus allowing most of the acid to flow into the flask. Upon closing the stop-cock of the funnel, the leveling reservoir was raised, and the flask was slowly heated until all the uraninite had dissolved. By withdrawing the flame for a moment some water was allowed to enter the flask and boiling was continued for about ten minutes. During the process of heating any occluded gas in the stem of the drop funnel was displaced with water by lowering the reservoir and opening the stop-cock of the funnel.

The remaining manipulations in boiling and transferring the gas to the electroscope were identical with those described for the "solution form" of sample.

SODDY and MCKENZIE APPARATUS

Plate 3 shows the construction of the Soddy-McKenzie apparatus for boiling off the emanation in vacuo and collecting it, with a modification for avoiding the entrapping of emanation in the connecting tubes.

PLATE 3

An auxilliary arrangement for transferring the collected emanation from the Soddy-McKenzie apparatus to the electrosopes is shown in another plate.

Each section of the apparatus was of glass construction, and all connections excepting one, were glass connections fused together, thus obviating the use of rubber connectors and possibly a "leaky" apparatus.

The apparatus was assembled as follows: A Töpler¹⁴ mercury pump, A, previously designed and constructed by Dr. Schlundt, was fused to a glass stoppered U-tube, B, containing dry, fused calcium chloride. The U-tube, B, was in turn fused to another U-tube, C, containing concentrated sulphuric acid, and to a two-way glass stop-cock, D. A long condenser, E, was fused to the stop-cock, D, and was connected to the sample flask, F, at the lower end by means of a glass stop-cock, G, passing through a one-holed rubber stopper, H.

Flask, F, was placed in a water-bath kept warm, but not boiling.

U-tubes, B and C, together with the phosphorus pentoxide tube, J, of the pump, constituted an excellent drying train for the emanation as it passed through the exhausted apparatus to the outlet, I.

Plugs of glass wool were placed in the U-tube, C, for the previous mentioned reason.

Stop-cock, D, communicated either with the outer air

¹⁴ Travers, M.W., Study of Gases, pp.5-10.

or with the two halves of the apparatus.

The emanation was collected over mercury at I into a mercury filled gas bottle (H, plate 4).

After collecting the emanation, it was transferred from the gas bottle to the exhausted electroscopes by means of the auxiliary apparatus shown in plate 4.

This apparatus consisted of a large hydrometer jar, A, filled with mercury, and a bent capillary tube, C, as shown fused to a two-way glass stop-cock. The gas bottle, H, capacity about 100 cubic centimeters, containing the collected gas and emanation and some mercury, was placed below the level of the mercury of the hydrometer jar, after which the capillary tube, C, was inserted into the gas bottle. Connection to the exhausted electroscope was made at E by means of rubber pressure tubing.

MANIPULATION OF THE APPARATUS

Manipulating the Soddy-McKenzie apparatus required more care and patience than the Schlundt-Moore apparatus. Before boiling off a sample with this apparatus, a blank test was made to insure a perfect working condition of all parts.

Being assured of this, stop-cock G was closed, D was opened to communicate with the apparatus, and all other stop-cocks were opened. The entire apparatus was then exhausted as perfectly as possible with the Töpler mercury pump. The sample flask was quickly attached to the tube containing the stop-cock, G, the water of the water bath having been previously warmed. The

gas collector (H, plate 4) was then filled with mercury and placed over the exit tube of the pump at I.

After an interval of about one minute had elapsed, stopcock G, was carefully opened and cold water was allowed to circulate through the condenser. On account of the diminished pressure in the flask, F, and the heat of the water bath, the contents of the flask immediately commenced to boil. Boiling was allowed to continue for about ten minutes, upon which stopcock, G, was closed. Any water which had been boiled off from the solution in the flask was re-condensed or taken up by the three drying agents contained in B, C, and J. But the emanation and other gases dissolved in the solution of the flask escaped into the apparatus between G and the mercury level at K.

By repeatedly raising and lowering the reservoir of the pump these gases were finally drawn into the gas collector at I, the mercury in the collector being displaced by the gases. Thus the apparatus became again exhausted to a high degree.

Stop-cock, G was then opened, and the solution in the flask once more commenced to boil. In this manner any gases, which might have possibly remained in the flask after the first boiling, were boiled off into the apparatus, and again collected into the gas collector at I. For every sample the solution was boiled in this manner three or four times in order to absolutely collect the last trace of emanation.

Stop-cock, D, was then slowly turned in order to gradually communicate with the outside atmosphere, thus allowing air to

enter the apparatus to the right of D. By raising and lowering the reservoir several times this air together with any gases remaining in the apparatus was collected into the gas collector.

Each time subsequent to boiling, stopcock, G, was closed. This prevented the rapid accumulation of moisture in the drying tubes, and also the vigorous shaking of the entire apparatus occasioned by each boiling. The gas collector, H, containing the gas contents of the sample and some mercury, was then transferred to the hydrometer jar of the auxiliary apparatus, plate 4. The mouth of the collector was placed below the surface of the mercury in the hydrometer jar, after which the thumb was removed from the opening of the collector.

With stopcock, D, closed, the capillary tube, C, was placed below the surface of the mercury and up into the gas collector to the very top, as shown.

The exhausted electroscope was then connected to the apparatus at E. D was slowly opened to the electroscope, the contents of the collector passed into the electroscope and the mercury was allowed to rise to stopcock, D, before it was closed. D was then opened to the air which swept the gases remaining in the tubes into the electroscope.

THIRD APPARATUS

Plate 5 shows in assembled form the scheme and general arrangement of the third type of apparatus used for the separation and transfer of the emanation from the samples to the electroscopes.

This form of apparatus was used in calibrating the Wulf

PLATE 5

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B (the sample flask) flowed into the aspirator, A. Screw-clip, L, was then ^{left} opened, and a slow but steady flow of air through B insured the complete transfer of gases or solution from the connecting tubes into the aspirator, A. Screw-clip, K, was closed, and the aspirator was disconnected at F and G. The aspirator was then ready for connection to the Wulf Electrometer.

Bottle, D, served as a trap for the back flow water from the filter pump, which consisted of an ordinary water suction pump.

Only the "solution form" of samples were used, and it will readily be observed that the transfer and collection of the sample was accomplished without the boiling necessary with the other two types of apparatus.

THE ELECTROSCOPES

Three instruments of widely different types were calibrated, namely, -- the Boltwood-Schlundt ¹⁶ electroscope, the Fontactometer of Mache and Meyer ¹⁷, and the Wulf Quartz-fiber Electrometer ¹⁸. They will be referred to as instruments Nos. 1, 2, and 3 respectively.

Instrument No. 1. This electroscope was a modification of the Boltwood form, and was designed and constructed by Prof. Herman Schlundt. It is shown in plate 6. It consisted of a rectangular brass frame with plate glass front and back, and provided with two large brass stop-cocks. A gold leaf was attached to a brass strip which terminated at the upper end in a narrow brass rod. This constituted the leaf system, which was fastened at the upper end into a hollow cylinder by means of sulphur serving as an insulator. This hollow cylinder was threaded so as to fit a brass ring which was fastened to the center of the top of the instrument. Thus by unscrewing the hollow cylinder the entire leaf system could be removed from the electroscope. A small brass cap was fitted over the projecting upper end of the brass rod of the leaf system, and served as a protection for the insulation.

The electroscope was provided with a reading microscope mounted in a collar soldered to a circular rod. A socket provided with set-screws held the collar in position. This gave the microscope a possible up-and-down motion or a forward-and-back-

¹⁶

Randall, M.; The Boltwood Standard of Radioactivity, Ibid. p. 477.

¹⁷ Mache and Meyer, Fontactometer; A Modification of the Fontactoscope of Engler & Sieveking.

¹⁸ Wulf, P.T.; L'Electrometer Bi-filaire et Applications; Physikalische Zeitschrift, 8, 246-8; 8, 527-30; 10, 251-3.

ward motion, or a circular motion in a horizontal plane. One adjustment of the reading microscope was made and retained through all the calibrations of the instrument, for a disturbance of the microscope would have necessitated a restandardization.

The brass flanges for the plate glass front and back of the instrument were carefully placed in order to afford a true plane for the plate glass to rest upon. It was found in the beginning that the plate glass cracked each time the instrument was evacuated to a high degree, and the cause was traced to the fact that the flanges were not in a true plane. This difficulty was subsequently obviated by accurately replacing the flanges as mentioned.

The glass front and back were secured airtight to the instrument only after encountering many obstacles and difficulties.

The following method was finally conceded as the best. By means of a small blow-torch and a stick of Kotinskie's cement, an even layer of the cement was spread over the flange. The instrument was placed on a hot radiator to soften the bed of cement, and the plate glass was put into position. A layer of the cement was then placed around the edges of the glass and burned firmly into place with the blow-torch. The electroscope was partially exhausted while the cement was softened with the torch. Thus the softened cement was drawn into the spaces between the glass and the edges of the electroscope, making a solid joint. Air-leaks in the instrument were ascertained by allowing a small amount of water to enter through one of the stopcocks, and exhausting. By properly revolving the electroscope in the hands the

water could be made to flow along any edge on the inside of the case. As soon as a leak was encountered it was indicated by the rising of air bubbles through the water. In this manner the exact position of the leak was known and immediately repaired.

As the ionization chamber of this electroscope also contained the leaf system, one objectionable feature will immediately become apparent. While exhausting the electroscope and while transferring emanation into it, the gold leaf was in grave danger of being blown off or otherwise injured, which necessitated the utmost care in manipulation. As the mounting of a gold leaf is a rather tedious operation, and as a change in the leaf meant a change in the electrostatic capacity of the instrument, it will be recognized that this was no small difficulty.

Instrument No. 2. This instrument, the fontactometer of Mache and Meyer, is a modification of the Fontactoscope of Engler & Sieveking. It is designed for determining the radioactivity of water samples in the field. The Fontactometer enables one to conduct these determinations in a simple manner. The instrument is shown in plate 7.

It consists of an Elster & Geitel electroscope, an electrode system and a zinc container (ionization chamber) of about 15 liters capacity. A calibration sheet accompanies the instrument giving the potential in volts corresponding to different divergencies of the leaves.

Figures A and B (plate 8) represent sectional drawings of the Elster and Geitel electroscope and the container. The rod

Plate 7

The diagram illustrates a mechanical assembly, possibly a pump or engine component, with a central rotating part. The main assembly is shown in a cross-sectional view, with various components labeled with letters. A central shaft or rod is labeled 'E'. The assembly includes a central chamber or cylinder, surrounded by various mechanical parts, including what appears to be a piston or plunger mechanism. The diagram is labeled 'PLATE 8' and includes a detailed view of a specific component, likely a valve or seal, labeled 'A'.

B

B

marked E-S, fig. B., shows the electrode system; E screws on to S at K (also see fig.A), a ground metal stopper, which can be securely fastened down by the catch R. The can is supplied with two stopcocks and two screw caps for the introduction of water samples. The electrode system is supported by the amber insulation at B. The supporting rod R on which the leaves are fastened is hollow to admit the stem S of the electrode when the electroscope is mounted on the can at M. The leaf protectors PP are shown drawn out. They should always be pushed home before the electroscope is moved about. The glass containers V_1 , V_2 for sodium are shown attached. Ordinarily these glass cups are kept in places provided for them in the carrying case, and are replaced by metal caps provided for the purpose. The cups for the drying agent -- metallic sodium -- need only to be used when the insulation has become defective on account of a film of moisture on the amber. They should be removed and replaced by the metal caps when the insulation is restored. The electroscope should not be set aside for an indefinite period with sodium in the caps, as there is danger of the alkaline solution that gradually accumulates being accidentally spilled into the interior of the electroscope. To charge the electroscope, pull out the protectors, remove the cap C, or the lid D, pull up the electrode to break metallic contact with the can, and then touch the stem S with one terminal of the Zamboni pile or apply an electrified vulcanite rod. Scale readings are made for the inner edges of the leaves. By reference to the curve sheet it is seen that a reading of 15.3 right and 15.4 left, or, 30.7 scale divisions, re-

present a potential of 202.7 volts.

Before beginning a calibration the insulation of the electroscope was tested. The amber of the electroscope must be dry and on humid days it was sometimes necessary to attach the sodium holders V V for a time to restore the normal air leak of the instrument. Considerable care was also taken to guard against radio-active products that may remain in the container from a previous determination. These disturbing factors were controlled by first measuring the normal air leak of the apparatus. For this purpose electrode E was screwed on the stem S provided with metallic stopper K. The electroscope was then placed in position on the can and the electrode raised to insulate it. Not until this stage were the protectors PP drawn back. The cap C was then removed and the leaf system at S charged by means of a Zamboni pile. Readings were taken for 15 minutes or half an hour. The normal air leak should not exceed 20 volts per hour. When a higher value than 60 was obtained the insulation was dried with absolute alcohol, fresh dust-free air was blown through the can with a hand bellows for several minutes, and the sodium holders were attached.

Quite a number of determinations of the air-leak were taken in order to become thoroughly familiar with the manipulation of the apparatus, and thus avoid the possibility of mistakes during the calibration of the instrument.

Instrument No. 3. This instrument was the Wulf Quartz-fiber Electrometer. In place of the leaf system of the ordinary electroscope a pair of silvered quartz fibers serve to measure the

fall of potential. This new device makes the instrument readily portable and enables the observer to make measurements even while the electrometer is being transported. Two wires are mounted in the same plane as the quartz fibers, and when earthed by screwing up the nut K_1 , figure 10 (plate 9) serve to keep the charged fibers by virtue of the induced charges always in the same plane. The binding post K_2 is used for making earth connections.

The insulation is amber, which must be dry and dust-free to insure perfect insulation. As seen in figure 10 and 10C (plate 9) the instrument is equipped with glass cups for holding sodium -- the drying agent. As the chamber enclosing the Quartz fibers is fairly air-tight the insulation rarely fails on account of moisture.

The eye-piece of the reading microscope is adjusted so that the scale is in focus and the zero of the scale should be adjusted by means of the milled screwhead, V_2 , to be midway between the fiber. The focus on the fiber is regulated by the milled sleeve V_1 of the microscope. Both fibers are generally in focus, but if the focus is not perfect the plane of the fibers can be twisted slightly by the screwhead V_3 , which operates slowly and turns the amber head.

The potentials corresponding to different scale readings were supplied by the makers, Messrs. Günther & Tegetmeyer. The curve sheet No. 3 shows the volts corresponding to the scale readings plotted as ordinates. Two sets are given: The smaller range of potentials, A and B, giving the volts for scale readings when the draw tube of the reading microscope is extended full length -- one scale reading representing approximately 1.5 volts

The other curves show the volts for scale readings taken with the draw tube pushed home, one scale reading representing approximately 2. volts.

The accessories of the electrometer consisted of:

- (1) A set of circular trays for the examination of solids.
- (2) Two rods, 9 cm. and 30 cm. long for use as electrodes besides the one shown in plate 9.
- (3) An ionization chamber of 2.6 liters capacity, including the aspirator and hand bellows.
- (4) A reel for wires upon which active deposits from the air have been collected.
- (5) An aspirator and hand bellows for determining the emanation content of water samples by the circulation method.
- (6) Several concentric cylinders for varying the electrostatic capacity.
- (7) A tripod and minor attachments.

Figures 10, 10A, 10B and 10C represent various mountings of the accessories of the instrument. The instrument was calibrated for the mounting shown in Fig. 10.

The accessories of the Wulf Electrometer enable the experimenter to use the instrument for various radioactive measurements. Some of the uses are as follows:-

- (1) Radioactivity of rain or snow.
- (2) Radioactivity of spring waters.

(3) Radioactive products of the atmosphere.

(4) Determination of thorium in rocks and minerals ¹⁹.

Eight combinations of the accessories are possible for radioactive measurements, thus giving eight corresponding electric capacities. The determination of the electric capacities is described in the memoir of Wulf.

²⁰
The Wulf Electrometer as assembled for calibration is shown in Plate 11. Plate 10 is a photograph of the instrument with all its accessories and the carrying case.

EXHAUSTING THE INSTRUMENTS.

An ordinary filter pump operated by water pressure was used in exhausting the three instruments. A water trap, consisting of a washing bottle of Raikow's form, was connected by the outlet tube to the filter pump, to prevent the back-flow of water from entering the ionization chamber of the instrument. The inlet tube of the bottle was in turn connected by strong rubber tubing to one of the stop-cocks of the instrument. The other stop-cock of the instrument was connected to a long glass tube resting in a jar of mercury which served as a vacuum gauge. The height to which the mercury was drawn up the tube showed the degree of exhaustion of the instrument.

¹⁹ Joly, J., Radioactivity and Geology.

²⁰ Wulf, P.T., Memoirs, Part 1, chapter 5.
Physikalische-Zeitschrift, volume 10, pages 253-4.
Harms, Physikalische-Zeitschrift, volume 5, page 47, 1904.

Plate 11.

When the fontactometer was being calibrated the exhaustion was accomplished by disconnecting the ionization chamber from the electroscope, and attaching the chamber to the exhaustion apparatus. The Boltwood-Schlundt electroscope was attached directly to the exhaustion apparatus. In exhausting the Wulf electrometer, the ionization chamber was secured to the electrometer by means of the provided clamps, and the entire instrument was attached to the exhaustion apparatus by means of the stop-cocks of the ionization chamber.

DETERMINATION OF THE E.M.F. OF
THE BATTERIES AND CALIBRATION OF THE
SCALES OF THE ELECTROSCOPES IN VOLTS PER DIVISION.

As a source of potential for calibrating the scales of the electroscopes in volts per division, two boxes of dry batteries, each containing 50 batteries of three cells each, and five standard batteries, each consisting of 20 Weston cells, were used. The dry batteries ²¹ were connected in series of rows of five, each box containing ten rows.

In order to accurately calibrate the scales of the electroscopes, the potential of the charging batteries was determined, not by direct voltmeter readings, but by means of the Clark-Poggendorf Method ²². The main reason for this consisted in the fact that the current used by the voltmeter caused an appreciable drop of the potential. It was later ascertained that there was quite an appreciable difference between the potentials as measured by voltmeter and those as measured by the Clark-Poggendorf method.

The Clark-Poggendorf method of measuring E.M.F.'s depends upon the principle of balancing the E.M.F.'s directly against one another by altering resistances, using a standard cell to balance against. This method is a valuable one, and possesses the great advantage over almost all others in being not only a "zero", but also a "null" method, i.e., while the E.M.F.'s are being compared

²¹

Columbia Flash Light Batteries No.03, made by National Carbon Co., Cleveland, Ohio.

²²Clark-Poggendorf Method of Comparing E.M.F.'s; page 96, Practical Electrical Testing, by G.D.A. Parr.

neither can possibly polarize, as no current passes through them.

Plate No. 12 represents a working drawing of the arrangement of apparatus for determining the potentials of the batteries by this method. E_1 represents a standard Weston cell with a voltage of 1.0186 volts; E_2 represents battery or batteries to be measured; r_1 and r_2 represent a resistance whose sum is constant, 10,000 ohms. The working battery E, consisted of 8 storage batteries connected in series. A sensitive galvanometer, G, and a two-way tapping key, K, are also shown in the drawing. An emergency resistance of about 10,000 ohms was placed between G and B.

The resistance r_1 and r_2 were so varied that on switching K to E_1 no deflection of the galvanometer occurred, and the value of r_1 was recorded. The resistances r_1 and r_2 were again adjusted so that on switching K to E_2 no deflection of the galvanometer was observed. The new value of r_1 was recorded as r_1^1 . According to Ohm's law $E_1 : E_2 :: r_1 : r_1^1$, from which the value of E_2 was readily calculated.

Each of the five sets of standard batteries was equipped with three terminals or binding posts, so that either one-half the voltage (about ten volts) or the entire voltage could be used. The voltage of each half of each of the five batteries was determined.

TABLE NO.4

E.M.F. of the Five Standard Batteries.

Cell No.	Halves	r_1	r_1^1	$E_1: E_2 = r_1: r_1^1$	E.M.F. of Battery
1	Right	720	7208	1.0186: $E_2 = 720: 7208$	10.197 volts
	Left	770	7810	" " = 770: 7810	10.33 "
2	Right	720	7237	" " = 720: 7237	10.236 "
	Left	770	7810	" " = 770: 7810	10.330 "
3	Right	719	7200	" " = 719: 7200	10.200 "
	Left	777	7810	" " = 777: 7810	10.230 "
4	Right	719	7210	" " = 719: 7210	10.214 "
	Left	781	7880	" " = 781: 7880	10.270 "
5	Right	780	7800	" " = 780: 7800	10.192 "
	Left	790	7940	" " = 790: 7940	10.230 "

Total voltage of the five batteries-102.41 "

Total voltage of 100 Weston cells,
if E.M.F. of each is 1.0186 - - - - 101.86 "

TABLE NO. 5

E.M.F. of Box 1 of Dry Cells.

Row No.	No. of Cells	r_1	r_1^1	$E_1: E_2 = r_1: r_1^1$	E. M. F. of Each Set
1	1st 3	694	9060	1.0186: $E_2 = 694: 9060$	13.29 volts
	Last 2	694	6004	diitto = 694: 6004	8.81 "
2	1st 3	702	9090	" = 702: 9090	14.36 "
	Last 2	700	6050	" = 700: 6050	8.52 "

TABLE NO. 5 (Continued)

E. M. F. of Box 1 of Dry Cells.

Row No.	No. of Cells	r_1	r_1^1	E_1	E_2	$E_1 = r_1 : r_1^1$	E.M.F. of Each Set
3	1st 3	695	9010	1.0186	E_2	$= 695:9010$	14.50 volts
	Last 2	695	6040	ditto		$= 695:6040$	8.85 "
4	1st 3	680	8955	"		$= 680:8955$	13.41 "
	Last 2	690	5980	"		$= 690:5980$	8.84 "
5	1st 3	678	8666	"		$= 678:8666$	13.02 "
	Last 2	690	5020	"		$= 690:5020$	7.41 "
6	1st 3	690	8970	"		$= 690:8970$	13.27 "
	Last 2	696	5020	"		$= 696:5020$	7.34 "
7	1st 3	697	9020	"		$= 697:9020$	13.20 "
	Last 2	697	6030	"		$= 697:6030$	8.81 "
8	1st 3	684	8930	"		$= 684:8930$	13.30 "
	Last 2	690	5770	"		$= 690:5770$	8.52 "
9	1st 3	704	9133	"		$= 704:9133$	13.22 "
	Last 2	700	5820	"		$= 700:5820$	8.47 "
10	1st 3	700	9062	"		$= 700:9062$	13.19 "
	Last 2	700	6070	"		$= 700:6070$	8.83 "

Total E. M. F. of Box 1 - - - - - 219.16 volts

Instead of taking the E. M. F. of each row as a whole, the E.M.F. of the first three and last two of each row was determined. This made it possible later to disconnect either two or three cells from the circuit when calibrating the scales of the electroscopes in volts per division, which insured a closer calibration of each scale.

TABLE NO. 6
E.M.F. of Box 2 of Dry Cells

Row No.	No. of Cells	r_1	r_1^1	$E_1; E_2 = r_1 : r_1^1$	E. M. F. of Each Set
1	1st 3	677	8820	1.0186; $E_2 = 677:8820$	13.27 volts
	Last 2	697	6077	ditto = 697:6077	8.88 "
2	1st 3	697	9057	" = 697:9057	13.23 "
	Last 2	697	6030	" = 697:6030	8.81 "
3	1st 3	700	8880	" = 700:8880	12.92 "
	Last 2	700	6120	" = 700:6120	8.91 "
4	1st 3	700	9174	" = 700:9174	13.35 "
	Last 2	704	5978	" = 704:5978	8.65 "
5	1st 3	700	8946	" = 700:8946	13.02 "
	Last 2	700	5915	" = 700:5915	8.61 "
6	1st 3	700	9074	" = 700:9074	13.20 "
	Last 2	700	5080	" = 700:5080	7.40 "
7	1st 3	700	9085	" = 700:9085	13.20 "
	Last 2	700	6090	" = 700:6090	8.90 "
8	1st 3	680	8730	" = 680:8730	13.07 "
	Last 2	684	5940	" = 684:5940	8.84 "
9	1st 3	688	8957	" = 688:8957	13.26 "
	Last 2	695	5248	" = 695:5248	7.69 "
10	1st 3	697	8994	" = 697:8994	13.14 "
	Last 2	697	6008	" = 697:6008	8.79 "

Total E. M. F. of Box 2 - - - - 217.14 volts

Considerable difficulty was encountered in determining

the voltage of the charging batteries, on account of a slight variation in the voltage of the "working" current E. This was almost entirely obviated by making all readings as rapidly as possible, and by slightly recharging the storage batteries, from which the working current was obtained, after every fifth or sixth reading. Immediately after re-charging, the voltage remained much more constant, and less difficulty was experienced in making readings.

The total voltage of the five standard batteries was 102.41 volts; the voltage of Box 1 and Box 2 of dry batteries was respectively 219.16 volts and 217.14 volts; giving a total E.M.F. of 538.71 volts from the three sources of potential.

The voltage of Box No. 1, as determined by direct voltmeter reading was 210 volts; that of Box No. 2 was 208 volts, showing an appreciable variation from the results obtained by the Clark-Poggendorf Method.

CALIBRATING THE SCALES OF
THE ELECTROSCOPES IN VOLTS PER DIVISION

Calibrations of the scale of instruments Nos. 1 and 2 were made -- that is, the Boltwood-Schlundt electroscope and the electroscope of the Mache-Meyer Fontactometer. The makers of the Wulf Quartz-fiber Electrometer furnished a calibration sheet with the instrument. This instrument was not recalibrated.

The arrangement of the apparatus for scale calibrations is shown in plate 13. The apparatus consisted of charging batteries A, B, C, and the electroscope D, whose scale is to be calibrated. A and B represent boxes Nos. 1 and 2 of dry batteries, and C represents the set of five standard batteries. The outer case of the electroscope was grounded, as was likewise the positive terminal of the batteries C. The batteries were connected in series, giving a combined voltage, when all were in use, of 538.71 volts. By touching the upper extremity of the leaf system of D with a wire connected to the negative of B, the electroscope became charged, and the voltage of the charge was immediately known by referring to tables Nos. 3, 4 and 5. By disconnecting the first three or the last two batteries of any row in boxes A or B, or by disconnecting one-half or an entire battery from C, the voltage could be varied within wide limits.

Instrument No. 1 was calibrated first. Batteries were disconnected from the charging boxes until the voltage was just sufficient to bring the leaf of the electroscope to the fifth or sixth division of the scale of the reading microscope. The scale

PLATE 13

It will be observed from the results of Set 2 that a fall of one division represents an average voltage of 1.13 volts for instrument No. 1. Randall's ²³ calibration of the scale of this instrument gave 1.03 volts per scale division. If the scale readings are plotted against volts in Set 2, the result is practically a straight line (See curve No. 1).

As has been shown by Schmidt ²⁴ and later by Randall ²⁵ the potential registered by an electroscope may not be proportional to the scale divisions. All calibration curves are not necessarily straight lines, as will be seen from the results of the calibration of the scale of instrument No. 2.

The scale of the electroscope of instrument No. 2 -- The fontactometer of Mache & Meyer -- was calibrated in the same manner as that of instrument No. 1. The electroscope was mounted on the ionization chamber of the fontactometer when the calibrations were made, and conditions were the same as those which prevailed when the instrument was calibrated in gms. U. per div.

²³

Randall, M., Ibid. p. 479

²⁴

Schmidt, H.W., Physik, Z., 7, 157 (1905)

²⁵

Randall, M., Ibid. p. 481.

TABLE NO. 8

MACHE-MEYER FONTACTOMETER

Scale Readings	:	Volts	:	Maker's Values-Volts	:	Volts Per Division		
L. : 3.8	----	7.8	:	66.33	:	68.1	:	-----
R. : 4.0	:	:	:	:	:	:	:	:
L. : 4.5	----	9.1	:	81.7	:	81.7	:	10.3
R. : 4.6	:	:	:	:	:	:	:	:
L. : 5.1	----	10.3	:	90.58	:	90.8	:	7.4
R. : 5.2	:	:	:	:	:	:	:	:
L. : 5.9	----	12	:	103.60	:	103.6	:	7.6
R. : 6.1	:	:	:	:	:	:	:	:
L. : 7.3	----	14.7	:	121.00	:	121.3	:	6.4
R. : 7.4	:	:	:	:	:	:	:	:
L. : 8.4	----	16.9	:	134.3	:	134.1	:	6.05
R. : 8.5	:	:	:	:	:	:	:	:
L. : 9.1	----	18.4	:	141.6	:	141.5	:	5.00
R. : 9.3	:	:	:	:	:	:	:	:
L. : 10.2	----	20.6	:	154.8	:	154.8	:	6.00
R. : 10.4	:	:	:	:	:	:	:	:
L. : 11.0	----	22.2	:	163.6	:	163.5	:	5.50
R. : 11.2	:	:	:	:	:	:	:	:
L. : 12.4	----	24.9	:	176.9	:	177.1	:	5.00
R. : 12.5	:	:	:	:	:	:	:	:
L. : 13.2	----	26.6	:	185.4	:	185.4	:	5.00
R. : 13.4	:	:	:	:	:	:	:	:
L. : 14.8	----	29.6	:	198.7	:	198.5	:	4.4
R. : 14.8	:	:	:	:	:	:	:	:
L. : 15.9	----	31.9	:	207.2	:	207.3	:	3.7
R. : 16.0	:	:	:	:	:	:	:	:
L. : 18.0	----	36.2	:	220.3	:	220.3	:	3.0
R. : 18.2	:	:	:	:	:	:	:	:

Volts

423 433 443 453 463 473 483 493 503 513 523 533 543

Scale Divisions

9 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

Curve No. 1
- Scale Divisions Plotted Against Potentials -
Boltwood-Schlundt Electroscope

The figures in the third column of the table show conclusively that the value of a division in volts depends upon what part of the scale the division happens to be. This value can be determined from a curve obtained by plotting scale divisions against voltage. Curve No. 2 represents these values -- volts per division -- for the electroscope of instrument No. 2.

DETERMINATION OF THE CAPACITY OF THE ELECTROSCOPES.

For determining the capacity of the electroscopes, a calibrated Harmes ²⁶ condenser was used and the method of Harmes was employed. The Harmes condenser consists of an inner cylinder supported upon an amber block, surrounded by an outer cylinder insulated by vulcanite. The inner cylinder is provided with an electrode which projects through an opening in the outer cylinder. The whole is enclosed in a metal case, which is kept grounded in order to avoid outside electrical disturbances.

The same source of potential was employed as was used in calibrating the electroscopes in volts per scale division.

The joint capacity of the leaf system and the condenser was first determined as follows:-

The leaf of the electroscope was charged to the upper end of the scale, as shown in section A, plate 14. The corresponding voltage was noted and called V_1 . Then the outer protecting case (3) of the condenser and the leaf system of the electroscope

²⁶ Harmes, F.; Physik. Z. 5, 47 (1904); Instrument No. 2240 furnished by Gunther and Tegetmeyer of Braunschweig. Capacity charged by induction 42.5 cms.

Curve No. 3
- Scale Readings Plotted Against Potentials -
Wulf Electrometer.

Curve No. 2
- Scale Divisions Plotted Against Potentials -
Fontactometer - Mache and Meyer

was earthed as shown in B, plate 14, after which the outer cylinder (2) of the condenser was charged, and the inner cylinder (1) of the condenser was earthed. After waiting two minutes the earth connection (d) with the leaf system of the electroscope was broken as was likewise the earth connection (e) with the inner cylinder of the condenser. The connection (a) between the batteries and outer cylinder of the condenser was broken. In this way the condenser became charged by induction.

After the condenser became charged by induction, a wire (e), which was connected to the electrode of the inner cylinder, was touched to the leaf system of the electroscope; this charged the leaf system. The position of the leaf was noted and its corresponding voltage was called V_2 . The joint capacity of the leaf system and the condenser was calculated from the formula

$$K = \frac{C V_1}{V_2},$$

in which K represents the joint capacity and C the capacity of the condenser (= 42.5 centimeters).

TABLE NO. 9

JOINT CAPACITY OF LEAF SYSTEM (ELECTROSCOPE
OF INSTRUMENT NO.1) AND THE CONDENSER

Trial No.:	V_1	V_2	C	K (Joint Capacity)
1	550 volts	434 volts	42.5 cms:	53.8 cms.
2	536 "	422 "	42.5 "	53.9 "
3	538.7 "	422 "	42.5 "	54.2 "

After calculating the joint capacity, the capacity of the

electroscopes was determined in the following manner:-

The inner cylinder of the Harnes condenser was connected with the leaves of the electroscope; and the case of the electroscope, case of the condenser and outer cylinder of the condenser were earthed as shown in plate 15. The condenser was then charged by connecting the positive of the charging batteries to earth, and the negative to the inner cylinder of condenser as indicated, until the leaf was charged to the upper part of the scale of the electroscope, A. The position of the leaf was read, and the corresponding voltage called V_3 .

The leaf system was disconnected from the condenser, and the condenser was removed several feet from the electroscope. The position of the leaf was read and the corresponding voltage called V_4 . Then the leaf of the electroscope was earthed for about two minutes; the electrode of the inner cylinder of the condenser, A, was brought in contact with the leaf system again, and the position of the leaf on the scale was read. The corresponding voltage was called V_5 .

The capacity of the electroscope was calculated from the formula

$$C = K \frac{V_3 - V_5}{V_4},$$

where K represents the previously determined joint capacity, and C the capacity of the electroscope.

TABLE NO. 10CAPACITY OF ELECTROSCOPE OF INSTRUMENT #1

Trial No.:	V_3	V_4	V_5	K(cms.)	C (cms.)
1	550 volts	545 volts	445 volts	53.8	10.35
2	529 "	509 "	429 "	53.9	10.64
3	536 "	528 "	430 "	54.2	10.88

Average capacity for Electroscope of instrument No. 1
without cap, = 10.62 cms.

The results of the determinations of the capacity of
the electroscope of instrument No. 2 (Fontactometer of Mache &
Meyer) are shown in Tables Nos. 11 & 12.

TABLE NO. 11JOINT CAPACITY OF CONDENSER & ELECTROSCOPE No.2

Trial No.:	V_1	V_2	C (Cms.)	K (Cms.)
1	220 volts	176 volts	42.5	53.1
2	207 "	163 "	42.5	53.9
3	220 "	170 "	42.5	55.0

TABLE NO. 12CAPACITY OF ELECTROSCOPE NO.2

Trial No.:	V_3	V_4	V_5	K (cms.)	C (cms.)
1	220 volts	213 volts	176 volts	53.1	10.9
2	207 "	164 "	199 "	53.9	10.4
3	220 "	213 "	198 "	55.0	10.4

Average capacity of Electroscope No. 2 = 10.5 cms.
Maker's value of capacity " " " = 10.42 "

The different capacities of instrument No. 3 (Wulf Quartz-fiber Elektrometer) were not determined, but the capacity of the instrument, 3.7 cms., furnished by the makers was assumed in the calibrations.

EXPERIMENTAL METHODS OF CALIBRAT-
ING THE INSTRUMENTS.

Three distinct methods were employed in calibrating the instruments, Nos. 1, 2, and 3. In method No. 1 -- Boiling off emanation at atmospheric pressure -- the Schlundt-Moore apparatus was used; in method No. 2 -- Soddy-McKenzie Method --, the Soddy-McKenzie apparatus was employed; and in method No. 3 -- the transfer method -- the transfer form of apparatus was used. These three forms of apparatus have already been fully described.

Method No. 1:- This method was used in calibrating the three instruments. After the radium emanation had been boiled off from the standard samples of uraninite into the Schlundt-Moore form of apparatus, as previously described, the emanation was transferred into the exhausted electroscopes, whose normal air-leak had been previously determined.

In calibrating instrument No. 1, an initial reading of the rate of fall of the leaf was made about two to four minutes after the emanation had entered, and a maximum reading was taken after three to three and one-half hours. The time for the leaf to fall about fifty divisions was noted in taking maximum readings. After the readings for a given sample had been completed, the stop-cocks of the instrument were opened, and dry, dust-free air was drawn through by means of an ordinary filter pump. In order to render the air dry and dust-free it was first drawn through a bottle of concentrated sulphuric acid, and cotton plugs.

All readings on the instruments were made in a separate

room in which only the instruments were allowed; the boiling of the samples and transfer of the emanation was performed in the work-room, one floor below the measurement room, in which the measurements were made.

As a rule it required from one to two days for the normal air-leak of the instrument to be restored, after making a test.

Both the "solid form" and "solution form" of samples were used in this method and with this instrument.

TABLE NO. 13

DATA FOR CALIBRATING INSTRUMENT NO.1
BY METHOD NO.1

Nos.	Sam- ple used:	Normal Air- Leak; div. :per minute	Initial :Leak;div. :per min.	Maximum Leak :Division per :minute	Gms.U.per :(Initial) : x 10 ⁴	Gms.U.per :(Maximum) : x 10 ⁴
8	:	0.32	: 54.72	: 89.45	: 14.15	: 8.64
7	:	1.25	: 104.70	: 171.42	: 10.17	: 6.21
10	:	1.80	: 54.91	: 85.70	: 10.34	: 6.31
6	:	1.00	: 131.20	: 214.37	: 10.40	: 6.35
1 ¹	:	1.00	: 21.65	: 35.30	: 26.66	: 16.05
2 ¹	:	0.21	: 59.38	: 96.79	: 10.26	: 6.28
3 ¹	:	0.85	: 153.31	: 250.00	: 16.66	: 10.20
4 ¹	:	0.63	: 115.03	: 187.50	: 10.36	: 6.34
5 ¹	:	1.00	: 37.00	: 60.00	: 10.41	: 6.35

The results of samples 8, 1¹, and 3¹ (columns 5 and 6, table 13) seem to indicate loss of some of the emanation in the transfer to the electroscope. All the other results are fairly

constant.

Omitting the results of Nos. 8, 1¹ and 3¹, the average number of grams of uranium per scale division per minute (initial) is 10.32×10^{-4} , and the average number of grams of uranium per scale division per minute (maximum) is 6.31×10^{-4} .

The procedure for calibrating Instrument No. 2 by this method was identical with that necessary for instrument No. 1. The ionization chamber of the fontactometer (No. 2) was independent of the electroscope, and being made of weaker material could not be exhausted as completely as electroscope No. 1. An earlier attempt at greater exhaustion caused several small depressions in the sides of the ionization chamber of No. 2, and it was decided to exhaust to a height of from eight to ten inches of mercury only (according to the vacuum gauge used -- see page 36).

Since the electroscope of instrument No. 2 was provided with two leaves instead of one, the rate of fall of both leaves was measured and their sum taken as the number of divisions fall for the measured period of time. When making readings they were always made from the inner edges of the leaves.

Both the "solid form" and "solution form" of samples of uraninite were used in calibrating instrument No. 2 as in the preceding case, to determine the difference, if any, between the two forms of samples. The results of the following table (No. 14) seem to indicate no appreciable variation due to the two different forms.

TABLE NO. 14
DATA FOR CALIBRATING INSTRUMENT NO. 2
BY METHOD NO. 1.

Sample:	Normal Air:	Initial	:Maximum	:Gms.U.per	:Gms.U.per div.:
Used	:Leak; div.:	:Leak;div.:	:Leak;div.:	:div.per min.	:per min.(maxi-:
Nos.	:per minute:	:per min.	:per min.	:(Initial)x 10 ³ :	:(Initial)x 10 ³ :
16	: 0.2	: 1.41	: 2.28	: 4.81	: 2.80
15	: 0.16	: 3.40	: 5.70	: 4.85	: 2.92
11	: 0.40	: 9.50	: 15.20	: 4.53	: 2.78
5	: 0.30	: 9.60	: 15.20	: 4.63	: 2.82
16 ¹	: 0.18	: 1.00	: 1.50	: 4.88	: 3.03
15 ¹	: 0.16	: 0.55	: 0.84	: 6.87	: 3.93
14 ¹	: 0.13	: 3.33	: 5.60	: 4.99	: 2.98
13 ¹	: 0.13	: 7.06	: 11.25	: 4.73	: 2.86
10 ¹	: 0.15	: 4.14	: 6.70	: 4.69	: 2.85

Omitting the results of determination 5 (sample No. 16¹), the average for the fifth column is 4.76×10^{-3} , and for the sixth column is 2.86×10^{-3} .

Instrument No. 3, the Wulf quartz-fiber electrometer, was likewise calibrated by method No. 1, slightly modified.

Plate No. 16 shows the arrangement of the apparatus for modification of method No. 1. A and B represent the bulbs of the hand bellows of instrument No. 3, X the aspirator of the same instrument, and C represents the Schlundt-Moore form of apparatus.

After the emanation had collected in the burette, as described on page 20, the larger bulb, A, of the hand bellows was com-

pressed by laying a weight upon it, and E was then closed. Upon opening D, with the water reservoir held above X and the weight slightly removed from A, the water rushed up into the burette and displaced the emanation, forcing it into the bellows and aspirator, X. The bellows and aspirator were disconnected at F, and carried into the measurements room, where they were connected to the ionization chamber of the Wulf Electrometer (consult plate 11). The hand bellows was worked continuously and uniformly for one minute, thus bubbling the emanation through the ionization chamber and an initial reading of the leak was made. Another reading of the leak was made within fifteen minutes of the first. The second leak reading was made to correct for the active deposit of rapid decay that accumulates on the walls of the ionization chamber.

Before the second leak reading was made, the water of the aspirator was replaced by inactive water, and the bellows was worked to displace any remaining emanation, after which the aspirator and bellows were again connected to the instrument. At the time it was thought that the second leak reading represents 90% of the initial activity of the radioactive deposits. Hence the activity of the radioactive deposits is obtained by multiplying the second reading by 1.1. The second reading (after 15 min.) was not used as it is not definitely known that this second reading represents 90% of the initial activity of the radioactive deposits. The correction factors of Berndt²⁷ were used instead.

Another correction of the first leak reading had to be made in order to correct for the small amount of emanation remain-

²⁷

Berndt, Ann., d. Physik. 38, 958, 1912.

ing dissolved in the water of the aspirator, and in order to correct for the amount of water in the aspirator, etc. In order to make this second correction, the following factors had to be known:-

V -- The volume of the ionization chamber.

W -- The volume of water in aspirator.

V_1 -- The volume of air space above the water in aspirator.

V_2 -- The volume of hand bellows and connections.

t -- The temperature of the water.

a -- The coefficient of absorption of the emanation in water.

The following formula was used in making corrections for volume of ionization chamber, volume of water, volume of air above water and temperature of water.

$$L \times \left(\frac{V \cancel{+} V_1 \cancel{+} V_2 \cancel{+} a W}{V} \right) = I,$$

where L is the air leak for the given sample, and, a, is the solubility of emanation in water. The value of I includes the activity of both emanation and active deposit. The activity due to the emanation alone was obtained by multiplying I by the values of Berndt. The quantity $\left(\frac{V \cancel{+} V_1 \cancel{+} V_2 \cancel{+} a W}{V} \right)$ gave a factor of 3.25.

The volume of the ionization chamber of instrument No. 3 was 1000 cubic centimeters; the quantity of water taken into the aspirator in each determination was 500 cubic centimeters; the volume of the air space above the water in the aspirator was 600 cc. at (29° C.); the volume of the hand bellows and connections -- bellows just completely distended -- was 500 cubic centimeters; the temperature of the water varied and was recorded separately for each determina-

tion; and the co-efficient of absorption of the emanation in water was interpolated from the values of Hoffmann²⁸.

The following table (No. 15) gives the results of the calibration of instrument No. 3 by the first modification of method No. 1.

TABLE NO.15

DATA FOR CALIBRATION OF INSTRUMENT
NO. 3 BY METHOD NO.1.

Nos.	Sam- ple taken	:Normal Air: Leak;div. :per minute	:Initial :Leak;Div.: :per min.	: Second : Leak;div.: : per min.	:Corrected :Initial Leak: :Div.per min.	:Gms.U.per Div. :per min. :Initial; 10 ⁴
17	:	0.28	4.24	0.51	10.30	5.82
18	:	0.30	8.00	0.600	20.02	5.83
19	:	0.35	11.11	0.714	28.00	6.25
20	:	0.56	13.09	0.82	32.60	6.35
21	:	0.33	16.48	0.96	42.00	5.93
22	:	0.66	19.23	0.910	48.32	6.06
23	:	0.33	18.09	0.970	46.20	5.86
24	:	0.60	18.75	0.830	47.20	5.99

The average value for the last column of table 15 is 6.01×10^{-4} g. U. per div. per min. It will be observed that there is a greater variation between the results and that the average result of the last column is somewhat higher than the average result obtained by method No. 2 for the same instrument (see table 18). This seems to indicate a loss of emanation somewhere in the method.

Method No. 2:- The three instruments were calibrated by this method. The Soddy-McKenzie apparatus for boiling off emana-

tion in vacuo was employed; its construction is shown in plate 3, and its description and operation is given on pages 22-26.

Instrument No. 1 was calibrated by collecting the emanation from the sample as described, transferring the emanation to the instrument by means of the auxilliary apparatus (plate 4), and by making two leak readings for each sample, an initial reading, and a maximum reading after three and one-half hours.

After the maximum reading for each determination the emanation was displaced from the instrument by drawing dust-free and dry air through it, and the next determination was made only after the normal air-leak had been restored. Sometimes it becomes necessary to attach a tube of sodium to the instrument to remove the moisture from the inside.

As stated previously, the execution of this method required rapid and careful action, and previous to a determination everything had to be put in readiness, for a slight mishap would have meant the loss of a determination.

The results of these determinations are given in table No. 16, column 5, giving the grams uranium per division per minute (initial), and column 6 giving the same factor for maximum activity.

The average for column 5 is 10.32×10^{-4} and for column 6 is 6.28×10^{-4} . These averages compare very favorably with the averages for the same instrument calibrated by method No. 1, p. 53 the corresponding values being 10.32×10^{-4} and 6.31×10^{-4} .

Samples Nos. a, b, c and d were made up by M. Randall²⁹, from the same uraninite as the others, and had been stored for a period of four years. They were of the "solution form".

²⁹ Randal, M., Ibid p. 463.

TABLE NO. 16

DATA FOR CALIBRATION OF INSTRUMENT NO. 1 BY
METHOD NO. 2

No. Sample taken:	Normal Air Leak; div. per minute	Initial Activity; div. per minute	Maximum Activity; div. per minute	Gms. U. per Div. per min. Initial 10^4	Gms. U. per Div. per min. Maximum 10^4
39	0.31	11.3	18.5	10.57	6.59
4	1.00	240.0	391.2	10.44	6.39
40	0.40	6.9	11.2	10.23	6.16
a	0.60	10.0	16.1	10.23	6.20
b	0.43	14.23	23.23	10.30	6.24
c	0.55	8.15	13.11	10.27	6.21
d	0.55	15.83	28.85	10.22	6.21

Instrument No. 2 was calibrated in the same manner as No. 1, by method No. 2, and after each determination the ionization can was removed from the electroscope, the emanation was displaced by air, and the normal air leak was restored.

TABLE NO. 17

DATA FOR CALIBRATION OF INSTRUMENT NO. 2 BY METHOD NO. 2

No. Sample taken:	Normal Air Leak; div. per minute	Initial Activity; div. per minute	Maximum Activity; div. per minute	Gms. U. per Div. per min. Initial 10^3	Gms. U. per Div. per min. Maximum 10^3
34	0.14	6.66	10.70	4.50	2.76
e	0.18	1.49	2.30	4.51	2.80
f	0.21	4.11	6.41	4.55	2.86
g	0.19	1.02	1.53	4.51	2.79
h	0.21	1.75	2.71	4.51	2.78
i	0.20	2.85	4.50	4.60	2.80
J	0.17	5.30	8.57	4.58	2.80

Samples e, f, g, h, i and j had been stored for four years.

Column 5 averages 4.54×10^{-3} and column 6 averages 2.80×10^{-3} , while the averages for the same instrument calibrated by Method No. 1 were 4.76×10^{-3} and 2.86×10^{-3} respectively.

In calibrating instrument No. 3 by this method the aspirator and hand bellows of the instrument were discarded, and only the electrometer with the ionization chamber was used. The emanation was boiled off from the samples in the same manner as before (see pages 22-26), and was transferred by means of the auxilliary apparatus directly into the ionization chamber of the instrument, without the use of the aspirator and hand bellows. Connection of the ionization chamber to the auxilliary apparatus was made at one of the glass stop-cocks of the chamber (see plate 11) by means of strong rubber tubing, the ionization chamber having been previously exhausted.

This method differed considerably from method No. 1 for calibrating instrument No. 3, as it did away with corrections for volume of the ionization train, for temperature, for emanation remaining dissolved in the water of the aspirator, and for active deposits of rapid decay. The last correction became unnecessary since a reading for maximum activity was made, instead of after an interval of fifteen minutes.

It will be perceived therefore that method No. 2 did not deviate for any instrument, and that the basic principle of the method was the same for the three instruments, regardless of their construction.

The following table (No. 18) gives the results of the determinations on instrument No. 3, calibrated by this method.

TABLE NO.18

DATA FOR CALIBRATION OF INSTRUMENT
NO.3 BY METHOD NO.2.

Nos.	Sam- ple tak- en	:Normal Air :Leak; div. :per minute	:Initial Ac- :tivity; div. :per minute	:Maximum Ac- :tivity; div. :per minute	:Gms.U.per: :Div. per :Min. Ini- :tial;10 ⁴	:Gms.U. per :Div. per :Maximum; 10 ⁴
36	:	0.23	54.5	92.3	4.82	2.84
37	:	0.25	88.8	133.2	4.66	3.10
35	:	0.37	68.4	109.8	4.83	3.00
k	:	0.20	5.55	8.82	5.08	3.15
l	:	0.24	18.18	29.27	4.85	2.99
m	:	0.28	24.50	38.21	4.85	3.10
n	:	0.31	13.61	21.51	4.82	3.04

According to table No. 18 it follows that a fall of one division per minute represents an average value of 4.84×10^{-4} g. of uranium for initial activity, and an average value of 3.03×10^{-4} g. of uranium for maximum activity. These results do not agree very well with those obtained for the same instrument by method No. 1; obviously the discrepancy in the results is due to a loss of some of the emanation by method No. 1, thus giving higher values for this method for instrument No. 3.

Method No. 3 for calibrating was suggested by Dr.Schlundt, but was used with instrument No. 3 (The Wulf Quartz-fiber Electrometer]

only. The form of apparatus employed in this method is shown in plate 5, and the description of its operation is given on pages 26-28.

It will be perceived that this method obviated boiling the samples, collecting the emanation in a burette and transferring it to the instrument, as the entire sample, including the gases in it, was transferred directly into the aspirator of the electrometer (see plate 5). After the sample had been transferred, the screw clips of the aspirator were closed and it was connected in series with the ionization chamber and hand bellows of instrument No. 3 (see plate 11).

The hand bellows was worked to bubble the air of the circuit through the solution in the aspirator. Most of the emanation was thus displaced from the solution and circulated through the circuit. The remainder of the procedure was the same as for the calibration of instrument No. 3 by method No. 1 (see pages 56-59).

In each determination the aspirator contained a sufficient quantity of freshly distilled water to make a bulk of 500 cc. after the sample was transferred into it.

TABLE NO. 19
DATA FOR CALIBRATING INSTRUMENT
NO. 3 BY METHOD NO. 3

Nos. Sample Taken	Normal Air: Leak; div. per minute	Initial: Leak; div. per min.	Second: Leak; div. per min.	Completely corrected Initial: Leak; div. per min.	Gms. U. Per Div. per min. Initial; 10^4
26	0.32	7.11	0.44	17.75	4.84
27	0.30	8.19	0.55	22.6	4.82
28	0.37	11.37	0.86	26.8	4.85
29	0.30	13.14	0.92	33.4	4.82
30	0.37	14.91	0.98	37.8	4.97
31	0.35	20.58	1.06	52.60	4.84
32	0.46	10.23	0.81	25.4	4.88
33	0.35	21.42	1.08	54.8	4.92

Corrections had to be made for the volume of the ionization circuit (the volume of the ionization chamber was $10/26$ of the volume of the ionization circuit), for the emanation remaining dissolved in the solution of the aspirator, and for the active deposit of rapid decay formed on the walls of the ionization chamber.

The calculations were the same as for instrument No. 3 by method No. 1, and the same formula was used in making the corrections on the initial air leak.

The average value for the last column of table No. 19 is 4.87×10^{-4} g. U. per div. per min. This value agrees very well with that obtained by method No. 2, 4.84×10^{-4} , but not with the value obtained by method No. 1.

TESTS WITH SOLUTIONS OF RADIUM BROMIDE.

As a crucial test of all the determinations, the three instruments were again calibrated by method No. 2 (Soddy-McKenzie apparatus used), using as a source of radium emanation samples made up from the stock solution of radium bromide procured from Boltwood (see pages 10 and 11). The procedure for the three instruments was identical with the procedure followed for the calibrations by this method previously.

In the first two determinations it was found that the Erlenmeyer flasks, in which the radium bromide solution was stored, would not withstand the pressure of the atmosphere when the Soddy-McKenzie apparatus was exhausted, and the samples had to be transferred to 100 cc Jena flasks.

All the samples of radium bromide solution were stored for

3.83 days -- half period of radium emanation -- and therefore the leak readings of the instruments had to be multiplied by two.

Four determinations were made on each instrument, and the results were first expressed in gms. U. per div. per min. for comparison with the results obtained with the uraninite samples. The uranium equivalent of the samples was calculated by dividing the radium equivalent by 3.1×10^{-7} .

TABLE NO. 20

DATA FOR CALIBRATING INSTRUMENTS NOS.
1, 2 & 3 BY METHOD NO. 2, USING RaBr₂ AS A
SOURCE OF EMANATION

INSTRUMENT NO.1						
Sample No.	Normal Air: Leak; div. per min.	Initial Ac- tivity; div. per min.	Maximum Ac- tivity; div. per min.	Gms.U. per div. per min.: Initial, 10^4	Gms.U. per Div. Per Min., Max- imum; 10^4	
B	0.55	2.26	3.31	10.42	6.45	
E	0.63	2.52	3.69	10.40	6.43	
C ¹	0.56	2.09	3.04	10.43	6.45	
D ¹	0.50	2.15	3.20	10.45	6.40	

INSTRUMENT NO.2						
C	0.13	0.53	0.76	4.61	2.90	
F	0.15	0.72	1.05	4.67	2.95	
E ¹	0.13	0.505	0.73	4.61	2.88	
F ¹	0.13	0.445	0.63	4.65	2.93	

INSTRUMENT NO.3						
A	0.21	3.81	5.86	4.95	3.15	
D	0.28	4.30	6.58	4.89	3.12	
A ¹	0.28	4.00	6.10	4.95	3.11	
B ¹	0.25	3.49	5.28	4.92	3.16	

From table No. 20 the average gms. U. per div. per min. (initial) for instrument No. 1 is 10.42×10^{-4} , and for maximum is 6.43×10^{-4} ; the same factors for instrument No. 2 are 4.63×10^{-3} and 2.91×10^{-3} respectively; and for instrument No. 3 are 4.93×10^{-4} and 3.14×10^{-4} respectively.

By comparing the results of the columns of tables 13 to 20 inclusive, it will be observed that there is no striking deviations of the results when table No. 15 is not included. This comparison shows further that the results of the calibrations by means of standard radium bromide solutions agree extremely well with the results obtained by using standard uraninite solutions or samples. The slight differences in the results obtained by using the two different sources of radium emanation, cannot however, be attributed to experimental errors. These differences average about four per cent. Thirdly, a reference to the kind of uraninite sample used in the various determinations of the instrument shows that the "solid form" of sample of uraninite serves equally as well as the "solution form" (see pages 8-9-10), for calibrations of instruments.

Apparently, this establishes an extremely close relation between the Boltwood Standard of radium emanation and the Radium Bromide Standard used, proving conclusively that a uraninite mineral accurately standardized gravimetrically, furnishes a source of radium emanation for calibrations almost equally as good as a Radium Standard. The establishment of this relation is of vast importance, when one takes into consideration the fact that a uraninite mineral

is readily purchased and can as readily be standardized, while the purchase of a Radium Standard is much more expensive, and not as available. Thus the Randall sample of uraninite by these direct comparisons with a sample of standard radium bromide solution, which had been prepared from radium bromide standardized directly against the International Radium Standard, gives results that are from three to five per cent higher (column 4, table 21).

We now have all the data for expressing the calibration constants of the instruments in terms of the units specified in the introduction, where the object of the investigation was outlined.

The three instruments were calibrated so as to obtain five distinct factors for each. The factors were as follows:-

1. Grams uranium per division per minute.
2. Grams radium per division per minute.
3. Grams radium per volt per minute.
4. Ionization current in C.G.S.E.S.U.
produced by the radium emanation
in equilibrium with one gram of uranium.
5. Grams radium per C.G.S. E.S.U. of current.

Factor No. 1 was derived by dividing the uranium content of the sample used by the net fall of the leaf or leaves in divisions per minute.

Factor No. 2 was obtained by multiplying factor No. 1 by " 3.4×10^{-7} " -- the amount of radium in equilibrium with one gram of uranium.

Factor No. 3 was obtained by dividing the radium content of the sample by the net volts fall of potential per minute which the sample produced.

Factor No. 4 was derived from the formula,

$$I = \frac{C \times V}{300 \times \text{wt. of } U},$$

where C is the capacity of the instrument, and V the net fall of potential per sec. produced by the radium emanation in the sample.

Factor No. 5 was derived as follows:- The ionization current due to the radium emanation of each sample was determined by the formula, $i = \frac{C \times V}{300}$, where C is the capacity of the instrument, and V the net fall of potential per sec. The ionization current produced in each determination was divided into the radium content of the sample used in the determination. After the introduction into the electroscopes of the radium emanation, which had been boiled off from the standard samples of uraninite or radium bromide in the various forms of apparatus, as described in previous sections, the ionization was allowed to reach a maximum value, which required three to three and one-half hours. After this interval the time for the leaf or leaves to fall a given number of divisions in the eye-piece, -- usually from 100 to 50 in the case of instrument No. 1, from 14-14 to 12-12 in instrument No. 2, and from 50-50 to 40-40 in instrument No. 3 -- was noted with a stop-watch. As soon as the measurements on the emanation were completed the stop-cocks of the ionization chambers were opened, and a slow current of dry air led through the chambers.

From calibration curves Nos. 1, 2 and 3 the scale readings of the instruments were reduced to potential readings, from which the number of volts fall per sec. or minute was calculated.

From this result was subtracted the number of volts fall of potential per sec. or per minute (as required) due to the normal air leak, determined in each case just prior to the introduction of the emanation into the instruments. This gave the net fall of potential in volts per minute or second required in calculating factors 3,4 and 5 for the instruments.

A comparison of the average values obtained for the five factors of each of the three instruments is shown in table No. 21. Each factor as shown is an average of from six to twelve determinations, excepting where solutions of radium bromide were used, in which case only four determinations were made. The number of the instrument, the source of emanation and the method used are shown for each average factor.

Columns Nos. 4, 5, 6, 7 and 8 give the five factors for the instruments.

For various reasons, certain determinations were considered unreliable and were not considered in calculating the average factors.

TABLE NO. 21

TABLE OF COMPARATIVE DATA FOR THE
INSTRUMENTS.

1	2	3	4	5	6	7	8	
Instru- ment No.	Source of Emanation	Method used	Gms. U. per div. min. Maxi- mum; 10^4	Gms. Ra per div. per min. maximum 10^{11}	Gms. Ra per volt per min. maximum 10^{11}	I in C.G.S. E.S.U.	G. Ra per E.S.U. current $\times 10^7$	
1	U_3O_8	1	6.31	21.44	19.13	1.03	3.18	
1	U_3O_8	2	6.28	21.31	18.50	1.06	3.13	
1	$RaBr_2$	2	5.96	19.93	18.30	1.12	3.04	
Fontactometer	2	U_3O_8	1	26.82	91.08	17.71	1.11	3.04
	2	U_3O_8	2	28.63	97.10	18.78	1.04	3.37
	2	$RaBr_2$	2	26.54	90.00	17.52	1.10	3.08
Wulf	3	U_3O_8	1	3.90 ⁶	12.23	8.98 ⁷	0.83	3.93
	3	U_3O_8	2	3.03	10.29	6.65	0.98	3.39
	3	U_3O_8	3	3.12	10.42	6.68	0.96	3.41
	3	$RaBr_2$	2	2.91	9.73	6.42	1.04	3.12

Table No. 21 speaks for itself and is a comparative summary of the entire work in data form.

A glance at this table shows that the only large variation in results is due to the calibration of instrument No. 3 by

method No. 1. The five factors obtained for this instrument by this method do not agree closely with the factors for the same instrument by the other methods.

The first three factors and the fifth factor of instrument No. 3 by method No. 1 are too high while the fourth factor is too low by comparison with the other results. After examining the methods of calculating these factors, it becomes apparent that some radium emanation must have been lost in all the determinations by this method for this particular instrument.

Referrring back to the description of this method and its manipulation (as applied to this instrument), only one solution of this discrepancy in results is forthcoming. It seems that the manipulation of the apparatus is rather questionable, as the exhaustion of the bellows by compressing them evidently does not draw in all the emanation.

It was supposed that boiling off the radium emanation from the solutions in vacuo would show a decided difference in the results thus obtained from the results gotten by boiling at atmospheric pressure, but no such difference is evident from the figures.

This result is rather gratifying, as method No. 1 has been used for ten years in this laboratory in the calibration of electroscopes that have been used in determining the radioactivity

of water and gas samples and the radium content of rocks, minerals, etc.

The ionization current in C.G.S.E.S.U. in equilibrium with one gram of uranium obtained for instrument No. 1 by method No. 1 is 1.03 (Column 7, Table 21). The ionization current for the same instrument calibrated by the same method as obtained by Randall³⁰ is 1.34.

It is interesting to note the results for instrument No. 3 by method No. 3. This method was devised and used exclusively for the Wulf Electrometer, to ascertain whether or not boiling off the radium emanation was an actual necessity in calibrating instruments of this construction. The results seem to point to the fact that transferring the entire solution of the sample -- including the air above it -- into the ionization chamber, and subsequent bubbling, serves the same purpose as boiling off the emanation and then transferring it into the ionization vessel. However, it must be borne in mind that this method is attendant with the corrections mentioned previously.

On the whole the conclusions to this work are of an interesting nature and are given in the following summary:

1. The results show that instruments of widely varying type for radioactivity measurements can be calibrated by the same method with excellent results.

³⁰ Randal, M., Ibid. p. 439

2. The ionization current appears to be proportional directly to the quantity of emanation used in the calibration within the limits of these experiments. The ionization current is practically independent of the size and shape of the ionization chamber. This latter result is in direct opposition to the conclusions of Randall ³¹. Instruments in which the grams uranium equivalent to one division per minute varied widely, gave very nearly the same ionization current in E.S.U. per gram uranium.
3. In general, when calibrating instruments for radioactive measurements, The Boltwood Standard of Uraninite as a source of radium emanation gives results which vary by from three to five per cent from the results obtained by using a Radium Bromide Standard.
4. There is very little or no difference in the results obtained by using the "solution form" of uraninite or the "solid form" of uraninite.
5. Boiling off the emanation from solutions in order to collect and transfer it into electroscopes is not absolutely essential. If it is feasible and the construction of the instrument permits, the solution containing the radium emanation, and likewise the air above the solution, can be transferred completely into the ionization chamber. Then by bubbling the emanation can be circulated through the ionization vessel. After the proper corrections the results obtained are as correct as if the emanation had been boiled off, collected and transferred into the ionization vessel.
6. Boiling off in vacuo solutions of radium emanation is no more effective in expelling the emanation than boiling off at atmospheric pressure.
7. In calibrating the instruments in volts per division, the direct voltmeter readings of the source of potential were not used. The E.M.F. of each section of the source of potential was previously determined by the Clark-Poggendorf method.

8. The samples of uraninite -- solution form -- which had been stored for four years, gave approximately the same results as those which were stored for a month.

The experimental work of this investigation was conducted during the session of 1912-13 and during the summer session 1913.

In conclusion the author desires to extend many thanks to Professor Herman Schlundt, of the Department of Chemistry, University of Missouri, for his unfailing enthusiasm and interest, and for his many valuable suggestions in performing the work of this study.

Chemical Laboratory,

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May, 1914.

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